GPS Carrier-Phase Multipath Model Validation

Quarterly Review of the NASA/FAA Joint University Program for Air Transportation Research

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Sai K. Kalyanaraman

Dr. Michael S. Braasch

Avionics Engineering Center

Ohio University, Athens, Ohio

Project Sponsor: NASA/FAA Joint University Program

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Motivation

- Multipath is the dominant error source in high-precision (i.e., differential carrier-phase) applications of GPS
- Theoretical models of GPS pseudorange error due to multipath have been validated
- Prior to this effort, carrier-phase multipath models have received scant attention
- Prior efforts have completely ignored the effect of code tracking architecture

Objective

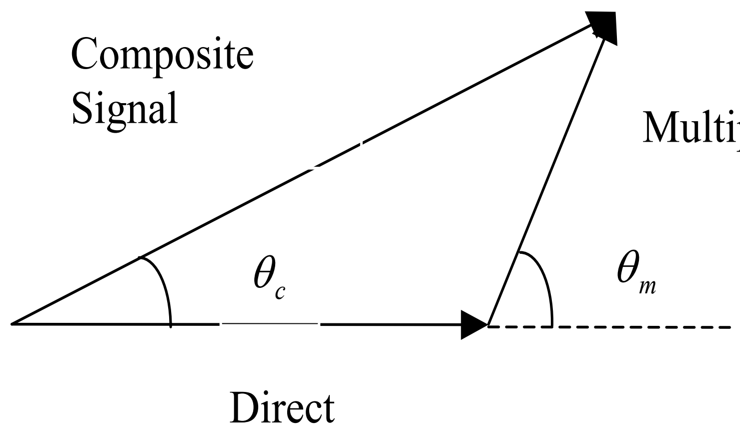
- Validate carrier-phase multipath theory
  - Validation of the currently published theoretical models against bench data
- Compare carrier-phase multipath errors between standard and narrow correlators
- Compare effects of coherent and non-coherent code tracking on carrier-phase multipath errors

Outline

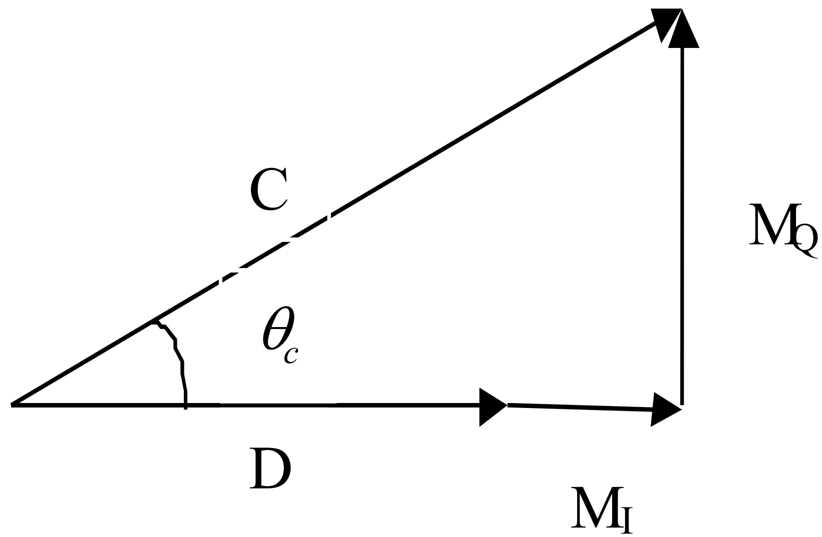
- Characterization of carrier-phase multipath
- Bench data collection setup
- Data analysis and validation
- Coherent versus Non-coherent code tracking
- Summary

Characterization of Carrier-phase Multipath

- Multipath parameters:
  - Amplitude
  - Delay
  - Phase
  - Phase-rate



Carrier-phase Multipath



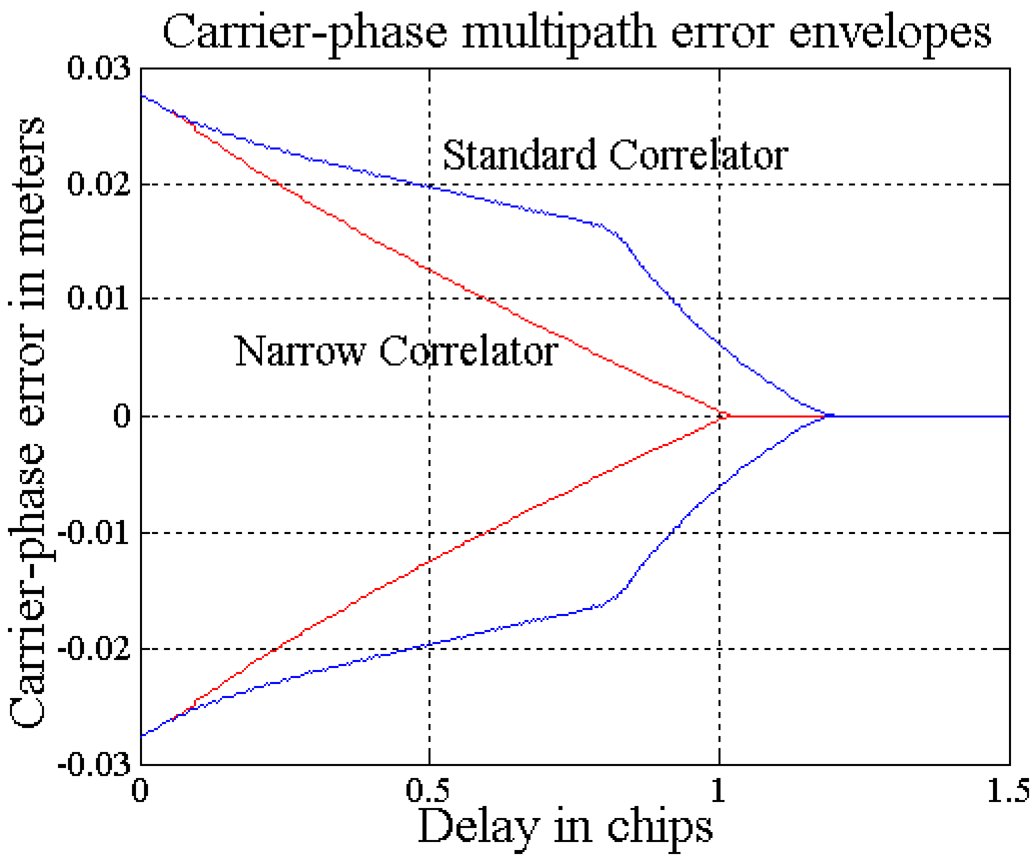
- Carrier-phase multipath error: $\theta_c = \arctan\left(\frac{M_Q}{D + M_I}\right)$

$$\theta_c = \arctan\left(\frac{\alpha R(\tau_c - \delta)\sin(\theta_m)}{R(\tau_c) + \alpha R(\tau_c - \delta)\cos(\theta_m)}\right)$$

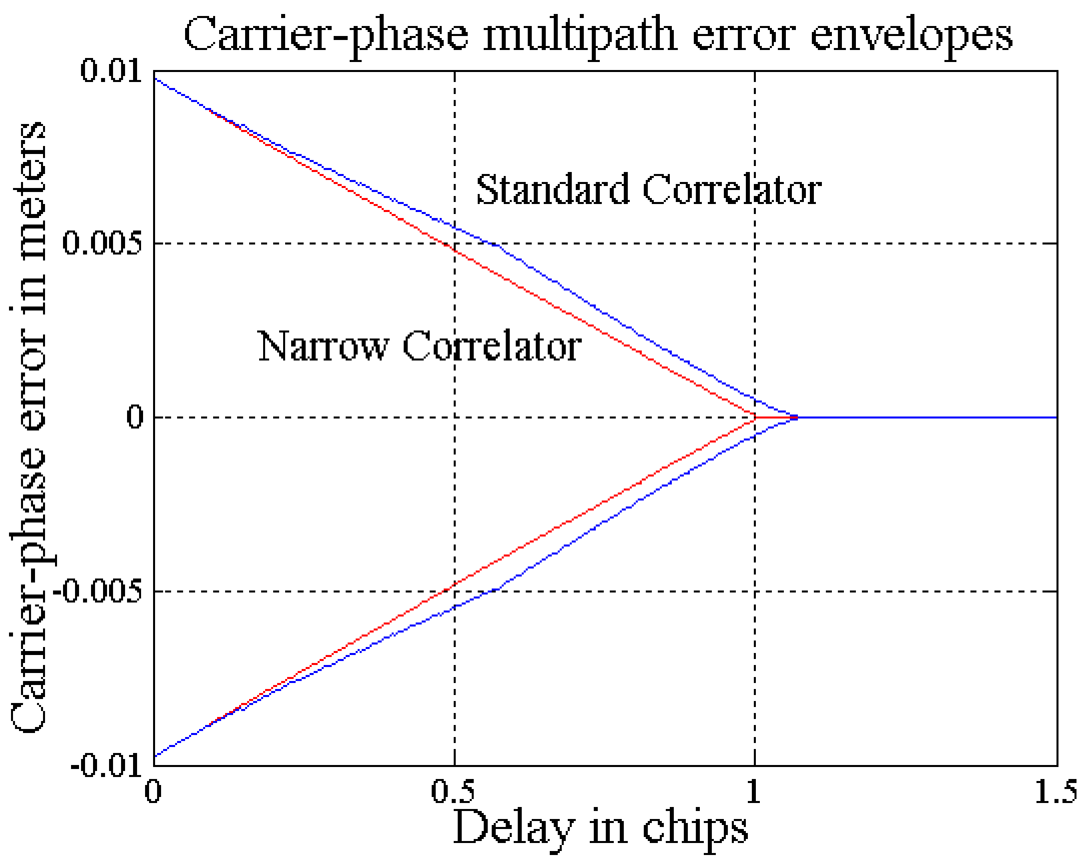
Parameters Under Consideration

- Non-coherent and Coherent code tracking
- Standard Correlator, 1.0 chip Early-Late spacing
  - Strong multipath M/D = -2dB
  - Weak multipath M/D = -10dB
- Narrow Correlator, 0.1 chip Early-Late spacing
  - Strong multipath M/D = -2dB
  - Weak multipath M/D = -10dB

Standard vs. Narrow Correlator; Non-coherent Code Tracking, M/D = -2dB



Standard vs. Narrow Correlator, Non-coherent code tracking, M/D = -10dB



Simplified Models for Carrier-Phase Multipath Error

- Maximum carrier-phase multipath error occurs when the multipath is orthogonal to the composite signal.

$$\theta_c = \arcsin\left(\frac{\alpha R(\tau_c - \delta)}{R(\tau_c)}\right)$$

- The above equation is difficult to implement in a simulation.

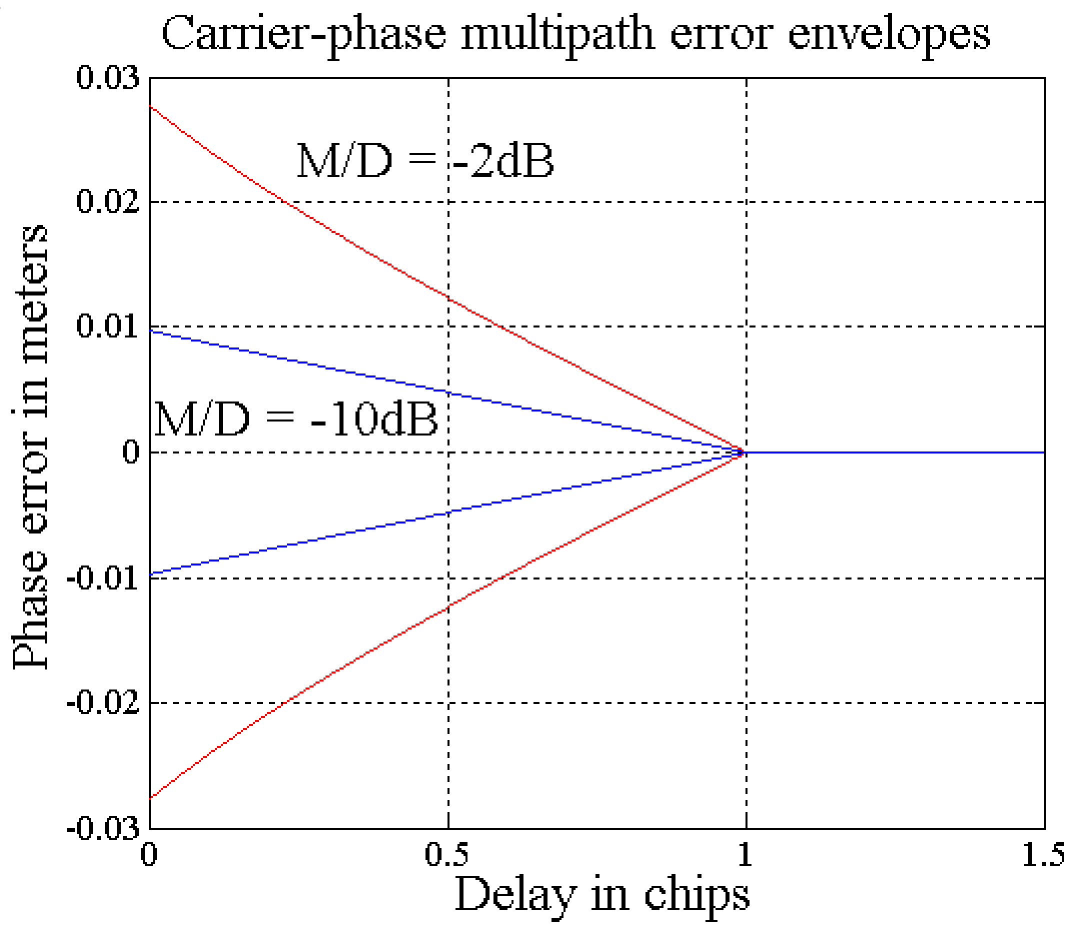
Simplified Models (continued)

- The orthogonal projection of the multipath component onto the composite is zero. Hence, for coherent code tracking, the code tracking error is negligible.
- The next model makes an assumption that the code-tracking error is negligible and further simplifies the previous model.

$$\theta_c = \arcsin\left(\alpha R\left(\delta\right)\right)$$

- However, it is possible to implement this simplified model.

Assumption: $\theta_c = \arcsin\left(\alpha R(\delta)\right)$



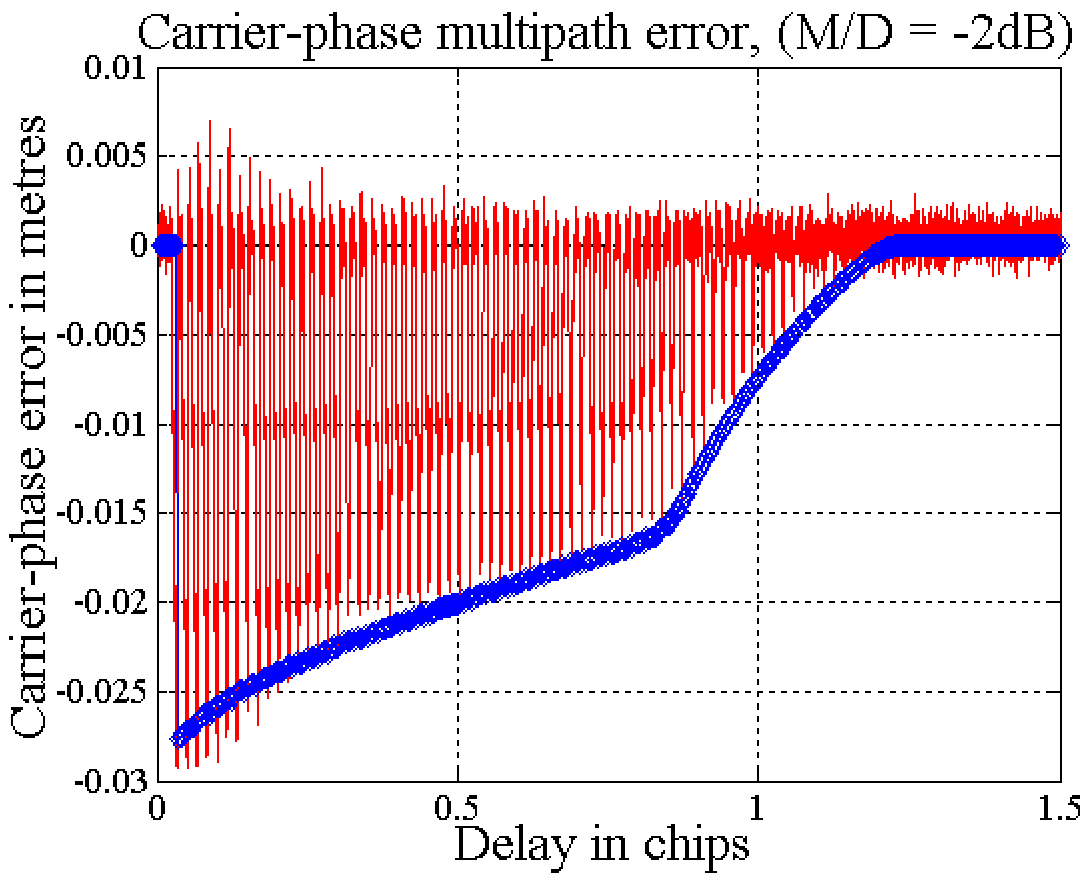
Bench-Test Setup

- GPS Hardware Signal Generator
  - Spirent/Nortel STR 2760
- Receiver
  - NovAtel OEM3 GPS Receiver with different software loads to implement standard and narrow correlators
- Two satellites simulated: one with multipath, one without; all other error sources (except noise) set to zero
- Differential processing to obtain multipath error

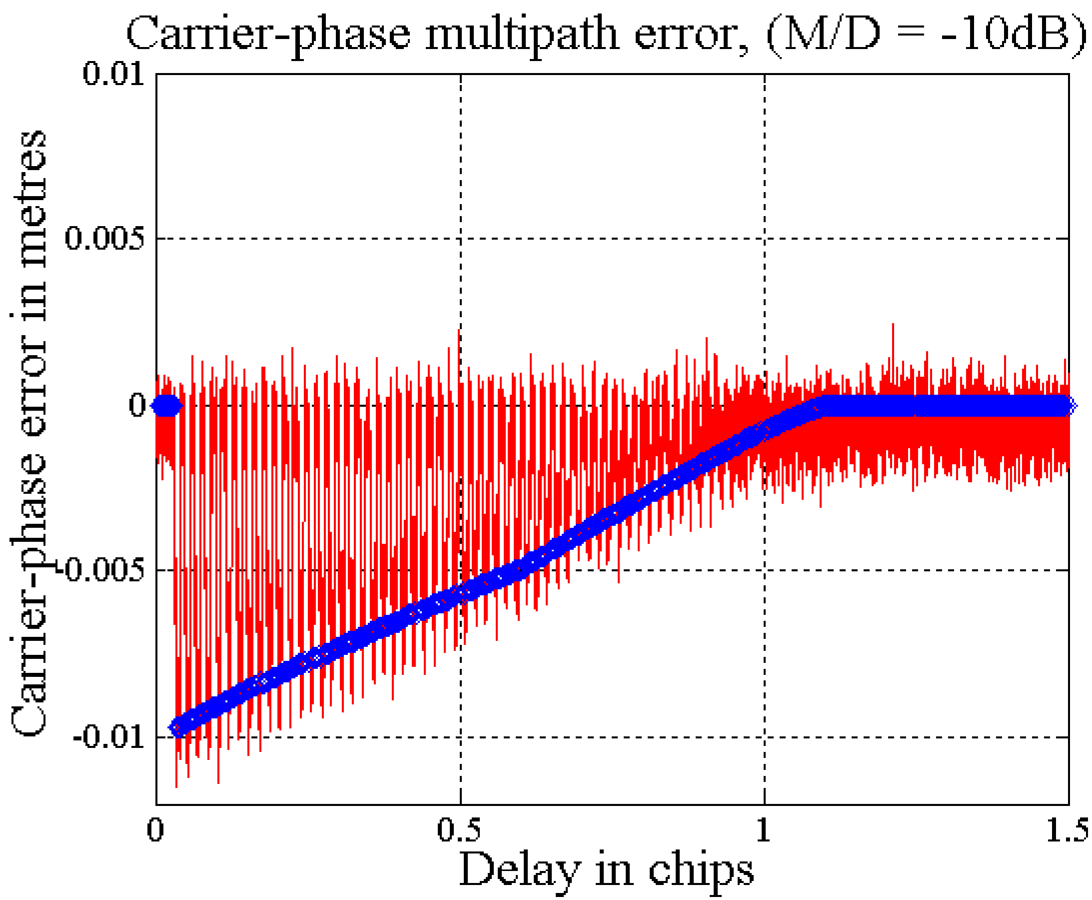
Data Analysis and Validation

- Data collected during the bench tests with standard and narrow correlator spacing was used to validate the theoretical multipath error envelopes.
- Comparison of bench test data with the theoretically obtained error envelopes was performed for M/D's of –2dB and –10dB.
- This attempts to capture the variations in the error envelopes between strong and weak multipath.

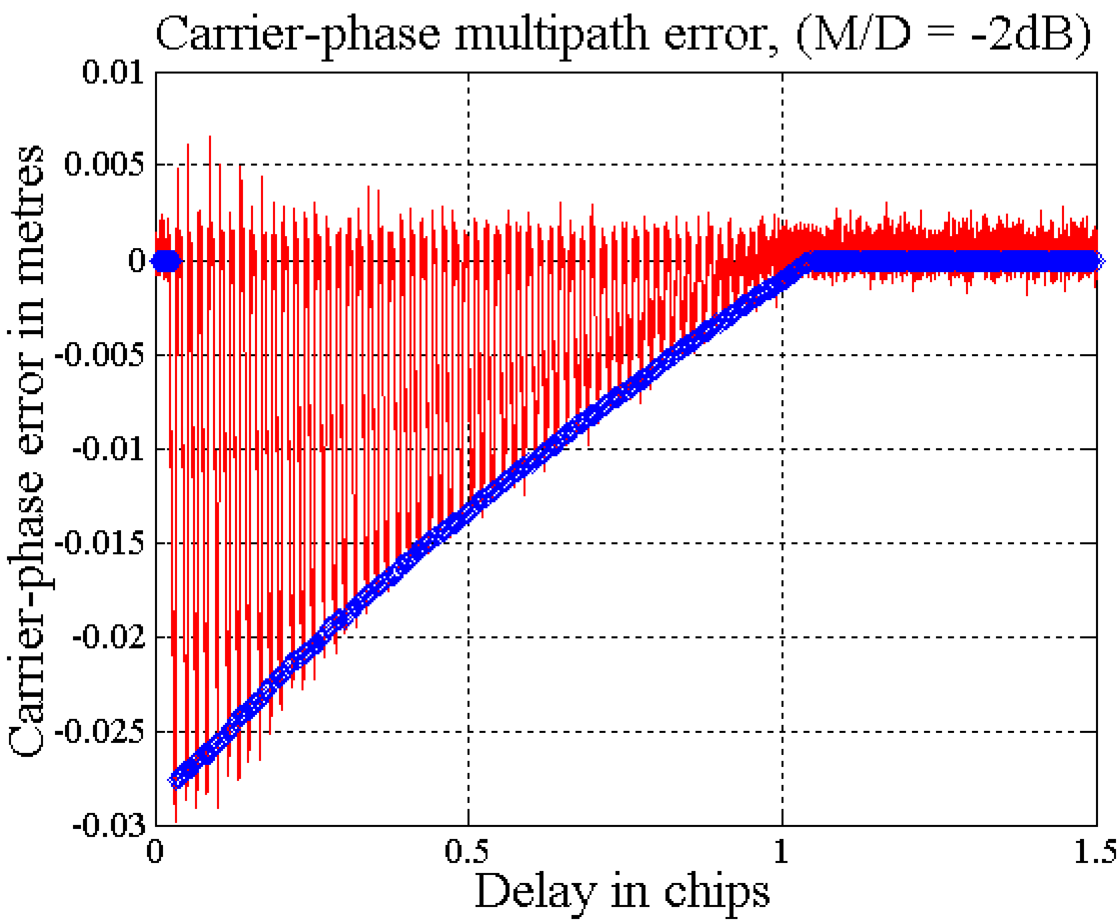
Standard correlator,Non-coherent code tracking. (Bench test data versus simulation results) M/D = -2dB



Standard correlator,Non-coherent code tracking. (Bench test data versus simulation results) M/D = -10dB



Narrow correlator, Non-coherent code tracking.
(Bench test data versus simulation results)
M/D = -2dB



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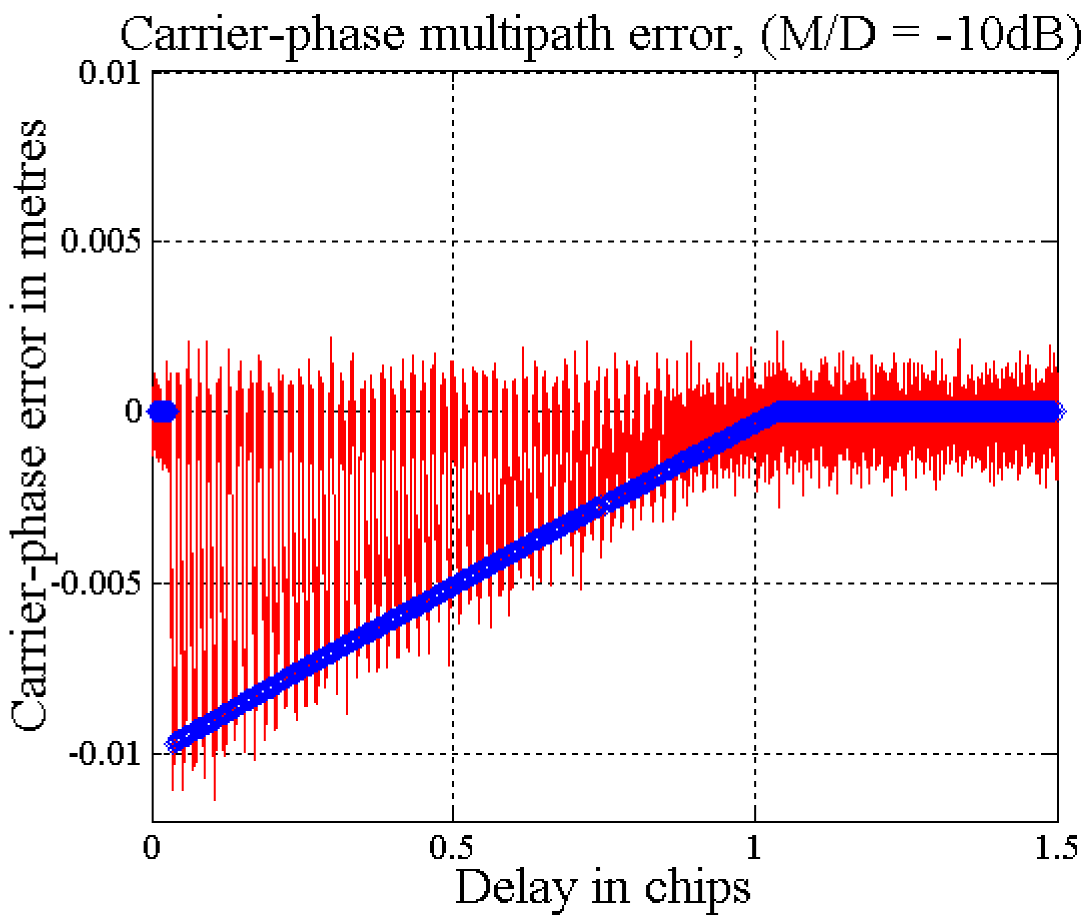
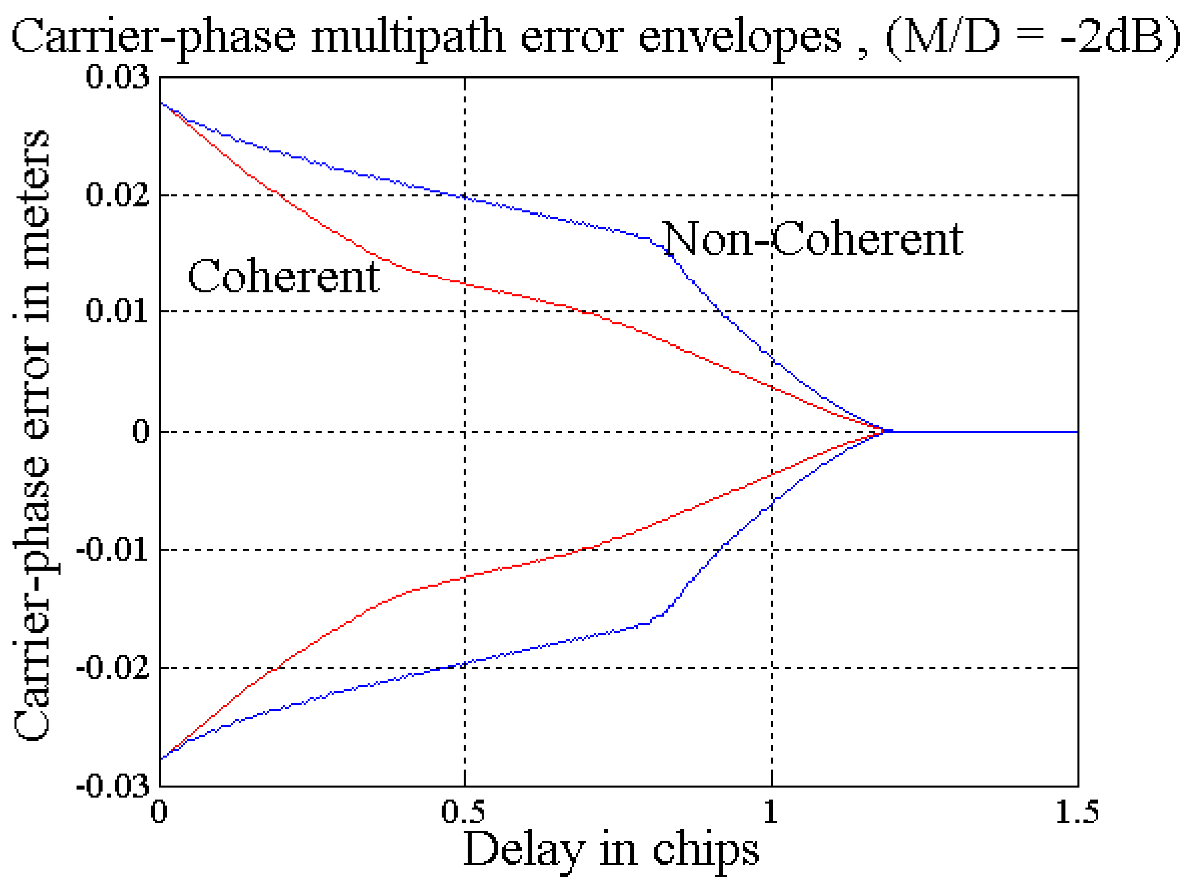
Narrow correlator, Non-coherent code tracking. (Bench test data versus simulation results) M/D = -10dB



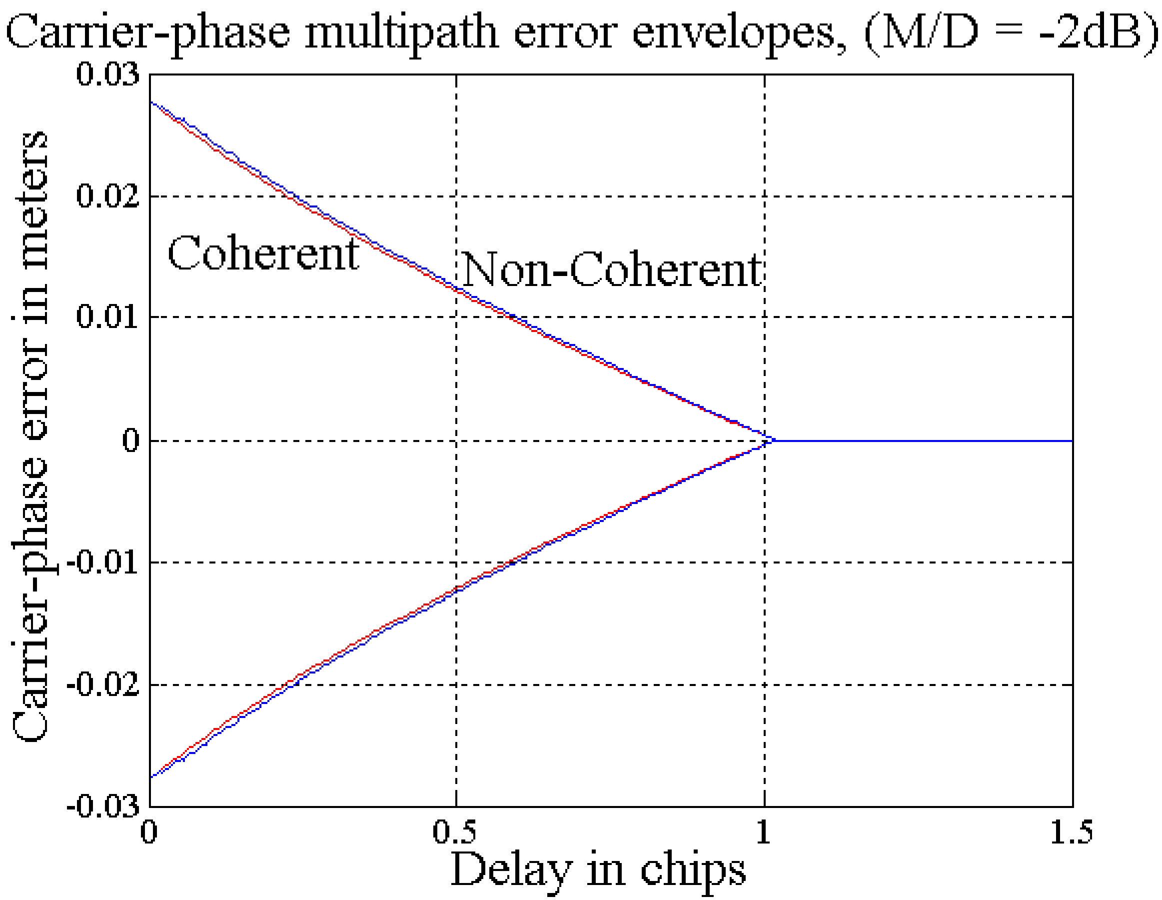
Effects of Coherent versus non-coherent code tracking on carrier-phase multipath error envelopes

- This validation of the carrier-phase multipath theory applies to the non-coherent code tracking mode.
- However, this section draws a comparison between the theoretical carrier-phase multipath error envelopes obtained for the non-coherent and coherent code tracking modes
- The standard and the wide correlator spacing architectures are compared for strong and weak multipath scenarios

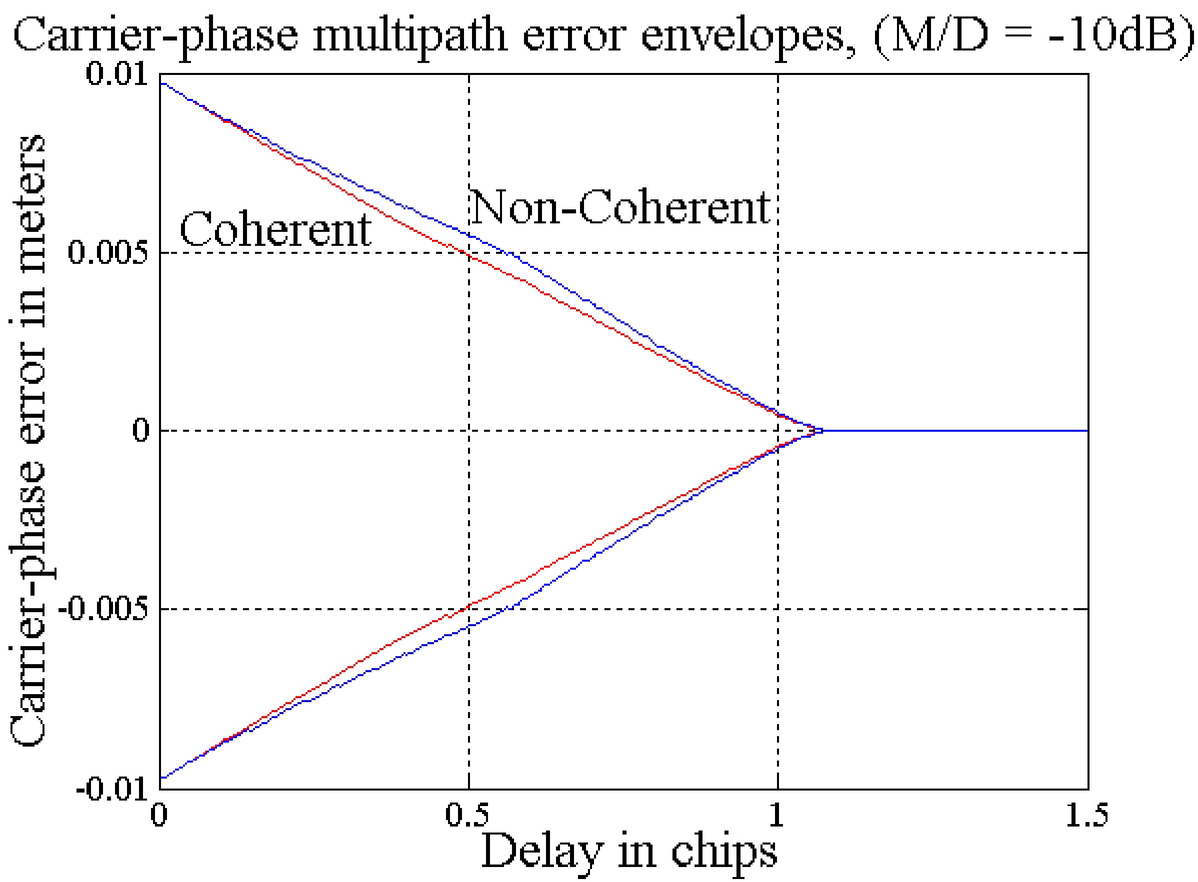
Standard correlator spacing, M/D = -2dB



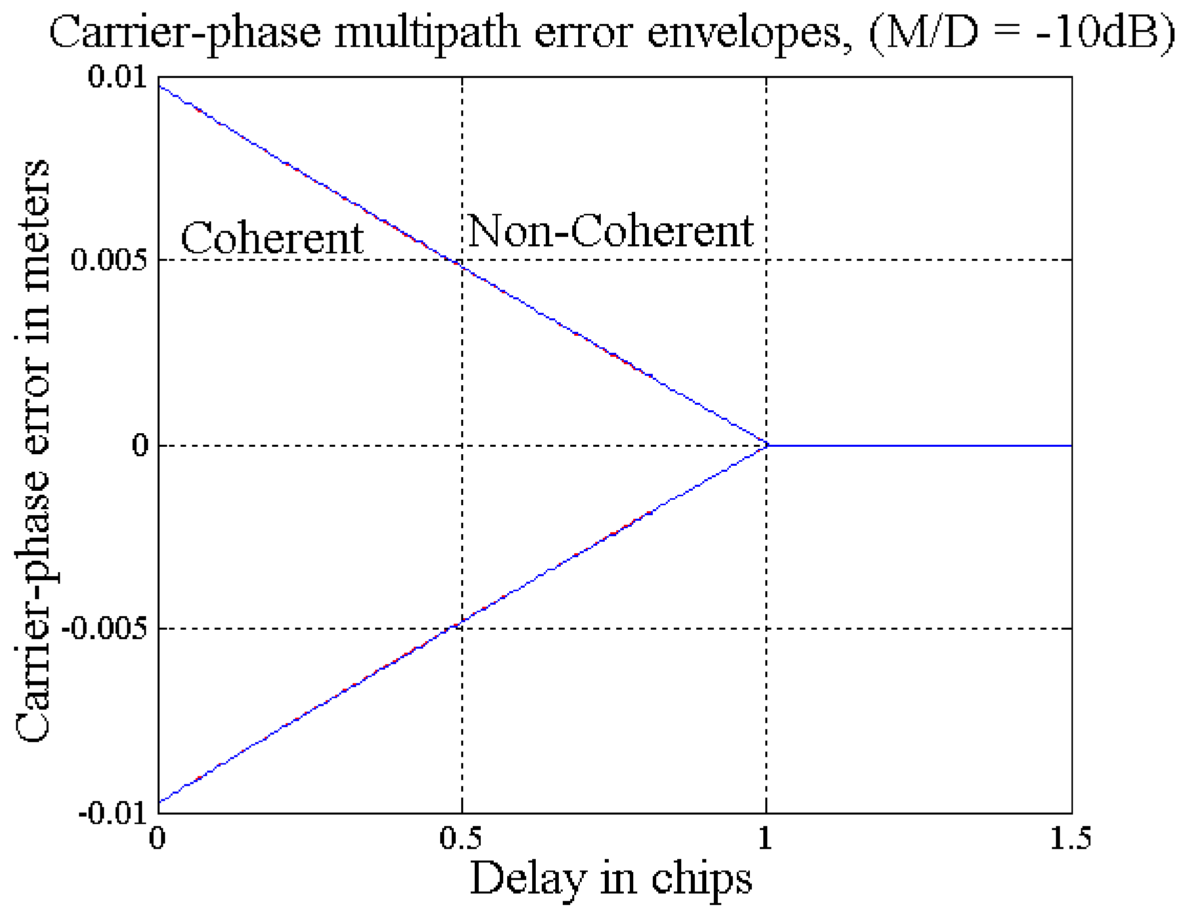
Narrow correlator spacing, M/D = -2dB



Standard correlator spacing, M/D = -10dB



Narrow correlator spacing, M/D = -10dB



Summary

- Theoretical carrier-phase multipath error envelopes have been validated for non-coherent code-tracking receivers
- Limitations in simplified models have been analyzed
- For carrier-phase multipath, narrow-correlator receivers significantly outperform standard correlators at high M/D
- Theory indicates additional carrier-phase multipath error envelope reduction for coherent code-trackers